

Status of the PICASSO Project

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The Picasso project is a dark matter search experiment based on the superheated droplet technique. Preliminary runs performed at the Picasso Lab in Montreal have showed the suitability of this detection technique to the search for weakly interacting cold dark matter particles. In July 2002, a new phase of the project started. A batch of six 1-liter detectors with an active mass of approximately 40g was installed in a gallery of the SNO observatory in Sudbury, Ontario, Canada at a depth of 6,800 feet (2,070m). We give a status report on the new experimental setup, data analysis, and preliminary limits on spin-dependent neutralino interaction cross section.

1. Introduction

The concept of dark matter has been around for almost a century. The most robust indication of the existence of this unique kind of matter, which is not susceptible to any interaction other than gravity and possibly a very weak interaction with ordinary matter, was the observed inconsistency between the rotation curves of spiral galaxies and their estimated amount of luminous matter.

The most recent results from WMAP satellite observations of the cosmic microwave background (CMB) [1] together with the observations of the relation between redshift and distance in type 1a supernovae [2] indicate that the total energy density of the Universe is, $\Omega_{total} = 1.02 \pm 0.02$ (flat Universe). These results also indicate that the two main constituents of the Universe are the dark energy, a new form of energy that contributes to the energy density of the Universe with $\Omega_{\Lambda} = 0.73 \pm 0.02$, and matter that contributes

with $\Omega_m = 0.27 \pm 0.04$. However, big-bang-nucleosynthesis predictions (supported by many observations including CMB measurements) indicate that the density of ordinary matter (baryon density) in the Universe is, $\Omega_b = 0.044 \pm 0.004$. This implies that most of the matter in the Universe is non-baryonic (dark).

The most promising non-baryonic candidate from the particle physics point of view is the neutralino, a weakly interacting massive particle (WIMP) that appears in many super-symmetric theories. The interaction of the neutralino with nuclei of ordinary matter is of electro-weak strength and can be either coherent or spin-dependent. Being a relic of the super-symmetric phase of the early Universe, the neutralino is expected to be found in halos of galaxies. In the case of our Galaxy, neutralinos are expected to have a Maxwellian velocity distribution with a mean velocity of ~ 300 km/s. At the Sun's position,

the expected energy density is $\sim 0.3 \text{ GeV/cm}^3$.

2. The Experimental Technique

Picasso detectors [3] consist of containers filled with droplets of a room-temperature superheated liquid (fluorinated halocarbons) dispersed in a gel. The interaction of a dark matter particle with an atomic nucleus in the droplets (i.e. fluorine or carbon) is expected to make the nucleus recoil. If the energy deposited by this recoiling nucleus within a certain length inside the droplet is large enough, bubble formation is triggered [4] and an explosive phase transition occurs. The resulting shock waves can be detected by piezoelectric sensors.

3. Picasso at SNO

In 2002, Picasso started taking data in the water purification gallery of the SNO underground facility at a depth of 6,800 feet. The setup consists of six 1-liter detector modules. The total active mass of the ensemble of detectors is $\sim 40 \text{ g}$. These modules are divided into 2 groups according to their superheated liquid composition: 3 so-called BD1000 detectors and 3 BD100 detectors. Due to the different compositions of the superheated liquids, these two groups of detectors have distinct operating temperature ranges. Therefore, the BD1000 and BD100 detectors are kept in two separate temperature-control systems (TCS) so that the temperature of each group of detectors can be regulated independently. The TCSs are surrounded by water cubes for neutron shielding.

The data acquisition system continuously monitors the piezos' output and triggers when a given signal exceeds the established minimum amplitude. It is worth mentioning at this point that, if left undisturbed, the droplets of superheated liquid are stable for indefinite periods of time.

Due to the nature of the detectors, data acquisition periods must be followed by a period of recompression so that the continuously growing gas bubbles, created by the explosive expansion of the superheated liquid droplets, can be brought back to the original droplet state. The best re-

sults have been achieved by setting 10 hours of recompression after 30 hours of data taking.

The detectors are fine tuned to detect dark matter particles. However, at the operating temperature range that the detectors have to be kept to detect dark matter optimally, they are also sensitive to neutrons and alpha particles, which make up the main particle background. The origin of the background particles can be internal or external.

The external background consists mostly of fast neutrons coming from the rocks of the walls of the cavern (cosmic ray induced neutrons are effectively attenuated at the depth of the cavern). These neutrons are relatively easy to avoid in the mine by surrounding the detectors with water cubes. The detectors are not sensitive to low-energy neutrons (nor to γ and β radiation) at the operating temperature range. Also, the setup was designed to be radon tight.

The internal background consists mainly of alpha particles produced in the decay chains of uranium and thorium present as contaminants in the constituents of the detector (and possibly radon contamination). These alpha particles are very difficult to remove as the level of contamination of the ingredients of the detector has to be lower than $10^{-10} - 10^{-11} \text{ g}$ per gram.

Figure 1 shows the data taken with one of the BD1000 (8g of active mass) detectors in our laboratory in Montreal and at SNO. The solid line depicts the response of the detector to the internal alpha background, which is an excellent fit for the data taken at SNO. The dashed line depicts the sum of the (dominant) external neutron background and the internal alpha background. This clearly shows that the data at SNO is dominated by the internal background.

Because the detector response is a threshold function [4] that is temperature dependent, data must be taken at different temperatures to cover the expected recoil energy spectrum. The data taking is divided into series that consist of a variable number of 30-hour sessions and 10 hours of recompression between them. During a series, the detectors are kept at a constant temperature that is usually different for the BD1000 and the BD100. On an individual event basis, it is impos-

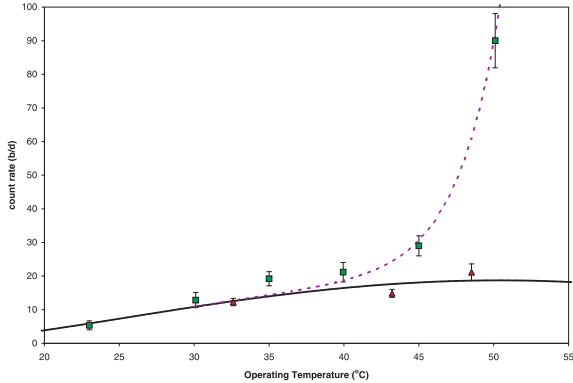


Figure 1. Comparison between the data taken in a paraffin shielding setup in Montreal (squares) and at SNO (triangles). The solid line is the expected alpha response of the detector.

sible to distinguish between the signal produced by the expected interaction of dark matter particles with the detector and the one produced by background particles. Due to that, lowering the overall particle background is critical. Besides, the background has to be well known so that a given enhancement in the count rate (beyond what is expected to be produced by the background) might be an indication of the interaction of dark matter particles with the detector.

Our data is consistent with an internal alpha particle background as shown by the measurements and Monte Carlo simulations [5]. Figure 2 shows the response of one of the BD1000 detectors to background measurements. Until November 2003, $\sim 1,700$ effective hours of data were taken at SNO. Due to the large spin-dependent cross section of the fluorine (present in the superheated liquid), we are able to obtain competitive results (for the amount of active mass). For a $M_\chi = 50$ GeV/ c^2 neutralino, cross section, $\sigma = 5pb$ is excluded at 90% C.L..

4. Conclusions

The setup in operation at SNO has proven to produce data of excellent quality. The main limitation is the internal alpha background due to

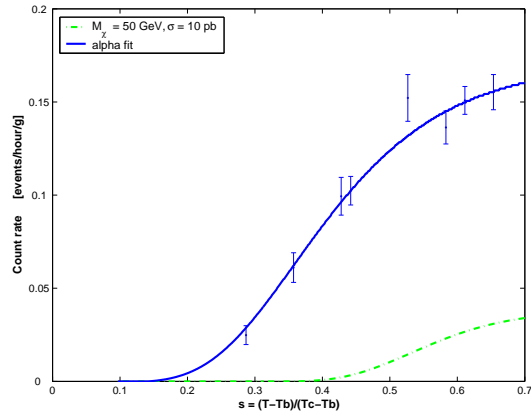


Figure 2. Response of a 7g-active-mass BD1000 detector at SNO as a function of the temperature expressed in terms of the reduced superheat, s [5]. The dash-dot line depicts the expected response of the detector to 10 pb, 50 GeV neutralinos. The solid line is a fit of the expected alpha response of the detector to the data.

radioactive contaminants in the ingredients of the gel. Presently, lowering the internal background is one of the main efforts of the collaboration. The plans for the future include the fabrication of larger detectors and the increasing of the active mass (a new capillary technique is in R&D stage). As an intermediate step to the fabrication of large detectors, a 10-liter prototype is expected to be ready in the beginning of 2004.

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